Water Supply Reallocation Workshop

Determining Yield and Space Requirement

Corp Guidelines

- EM 1110-2-1420 “Hydrologic Engineering Requirements for Reservoirs”
- EM 1110-2-1417 “Flood Runoff Analysis”
- EM 1110-2-1701 “Engineering and Design Hydropower”

Terms

- Yield – also know as firm yield and critical yield is the maximum sustainable flow at some point in time during the most adverse sequence of streamflow (critical period).
- Storage – water impounded in surface or underground reservoirs for future use.

Storage-Yield Relationship

- Two ways to view
  - The storage required at a given site to supply a given yield (planning)
  - Determine the yield from a given amount of storage (final design)

Purpose

- Storage requirements for
  - Water supply
  - Water quality
  - Hydroelectric power
  - Navigation
  - Irrigation
  - Other conservation purpose

Yield Objectives

- Determine yield given a storage allocation
- Find storage required given a desired yield
- Determination of complementary or competitive aspects of multi project development
- Analysis of alternative operation rules for a project or group of projects

Procedures

- Simplified
  - Mass Curve
  - Depth duration
- Detailed sequential analysis
  - Simulation analysis
  - Mathematical programming (optimization)

Selection

- Simplified
  - Constant demand, preliminary or screening studies
- Sequential
  - Feasibility and design phases
- Other factors
  - Available data, study objectives and budget

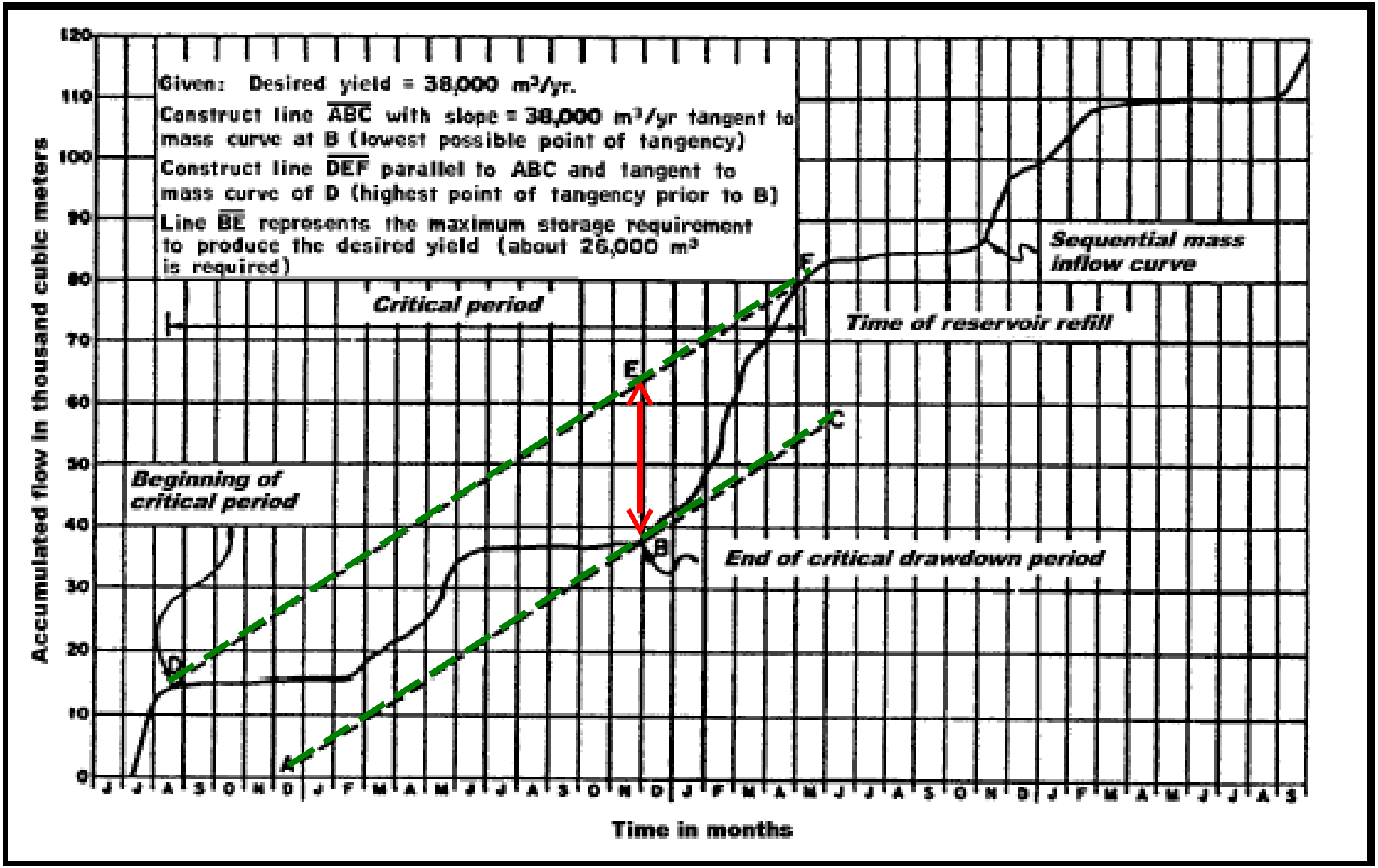
Simplified

- Sequential Mass Curve
  - Constructed by accumulating inflows to a reservoir site throughout the period of record & plotting the accumulated inflows versus the sequential time period
- Depth Duration
  - Relationship of storage yield vs shortage frequency

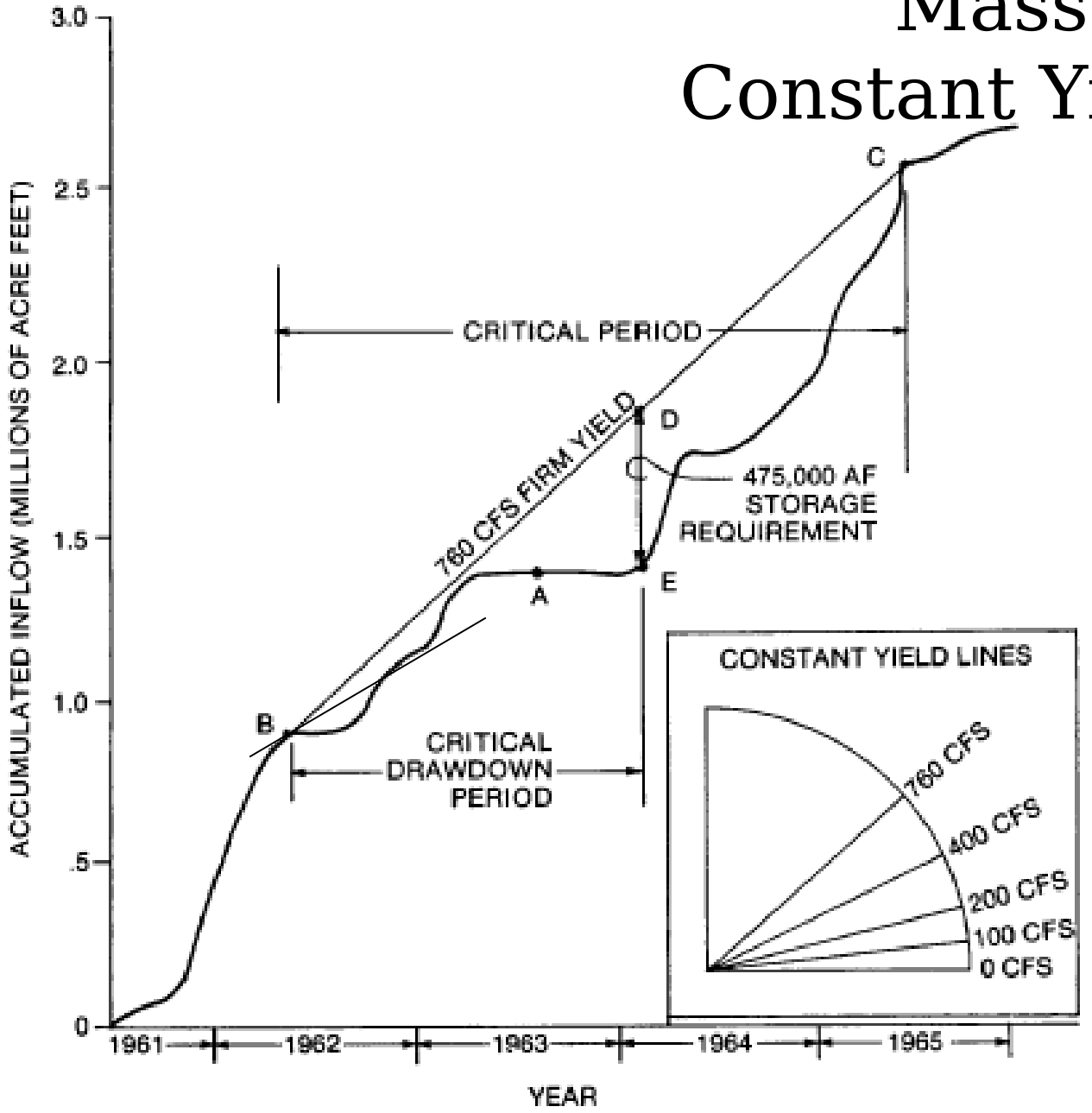
Sequential Mass Curve

- Manual graphical procedure used to identify the critical period and firm yield
- Firm yield is maximized by fully drafting available storage to supplement natural streamflow
- Mass curve is cumulative plotting of reservoir inflow
- The slope of the mass curve at any point in time represents the inflow at that time.

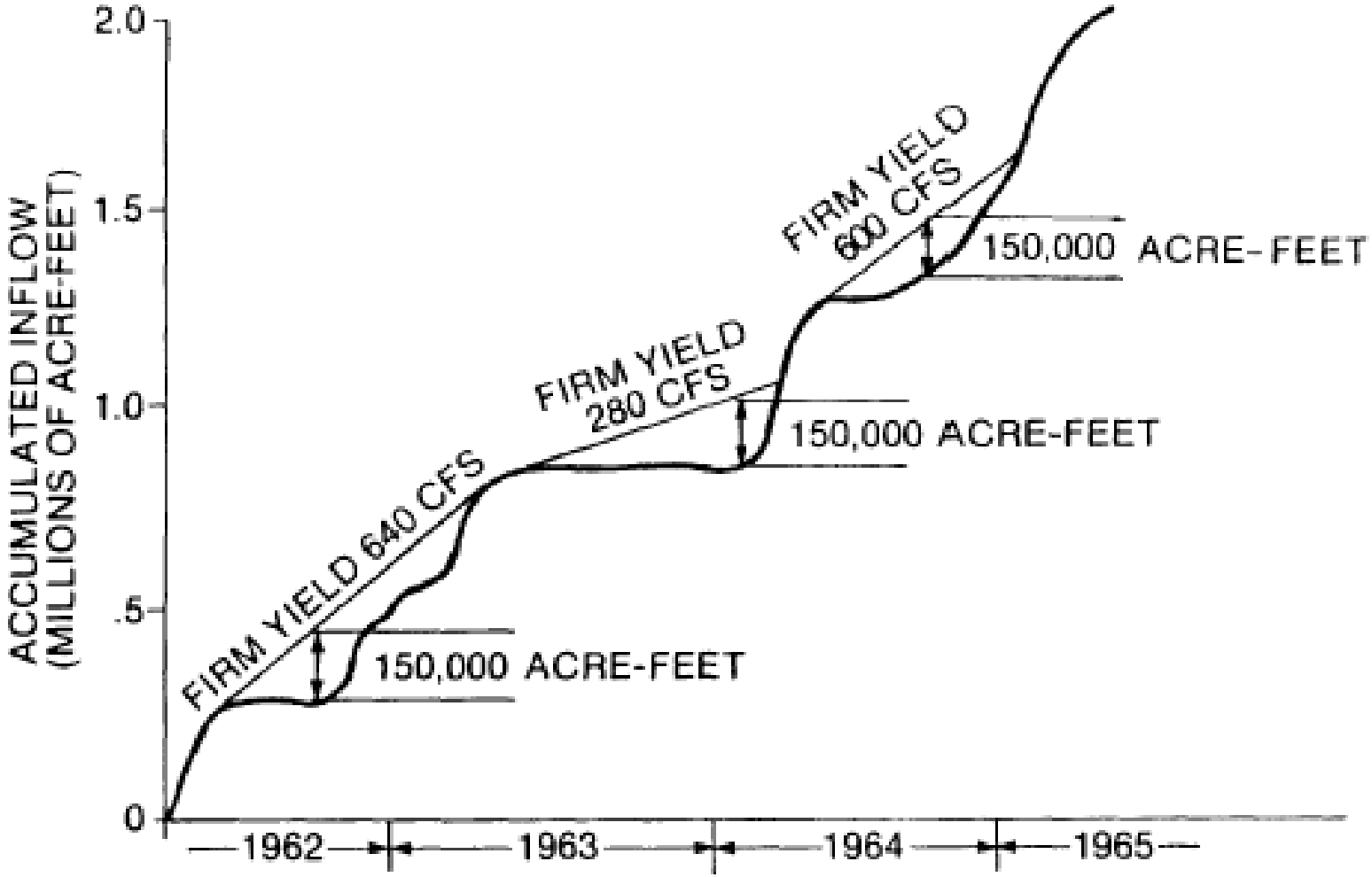
Sequential Mass Curve


Given: Desired yield = 38,000 m³/yr.
Construct line ABC with slope = 38,000 m³/yr tangent to mass curve at B (lowest possible point of tangency)
Construct line DEF parallel to ABC and tangent to mass curve of D (highest point of tangency prior to B)
Line BE represents the maximum storage requirement to produce the desired yield (about 26,000 m³ is required)
Critical period
Sequential mass inflow curve
Time of reservoir refill
Beginning of critical period
End of critical drawdown period
A
B
C
D
E
F
Accumulated flow in thousand cubic meters
0
10
20
30
40
50
60
70
80
90
100
110
120
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
Time in months

Mass Curve & Constant Yield Lines



Yield given Storage



Simplified Limitations

- Does not reflect seasonal variations in demand
- Inability to accurately evaluate evaporation losses

Detailed Sequential Analysis

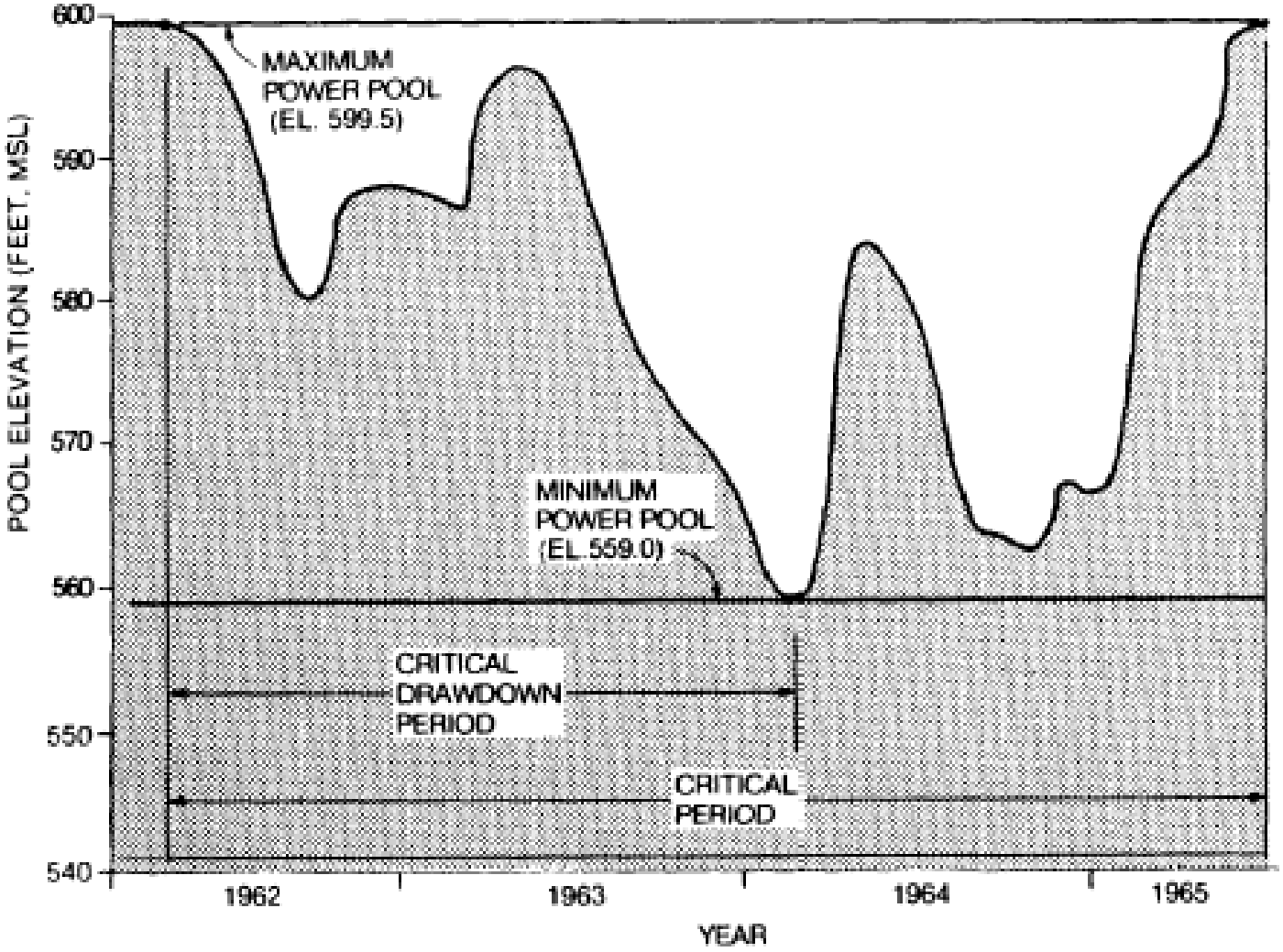
- Conservation of mass

  $I - O = \Delta S$

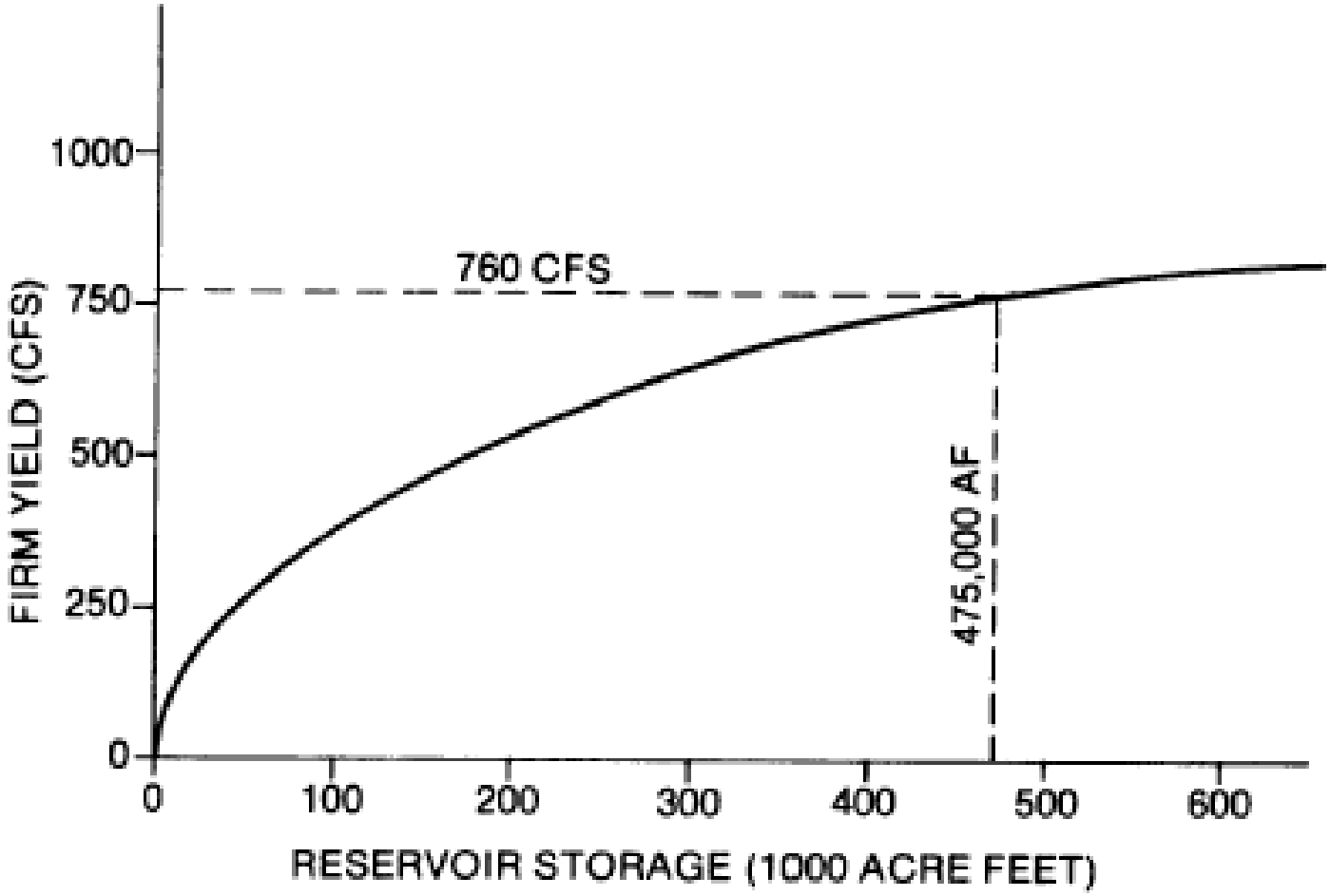
  I = inflow, O= outflow, ΔS=change in storage

- Computer Simulation (HEC-5, ResSim)
  - Multipurpose reservoir
  - Varying demand
  - Evaporation evaluation
  - Firm yield optimization

Maximize Firm Yield

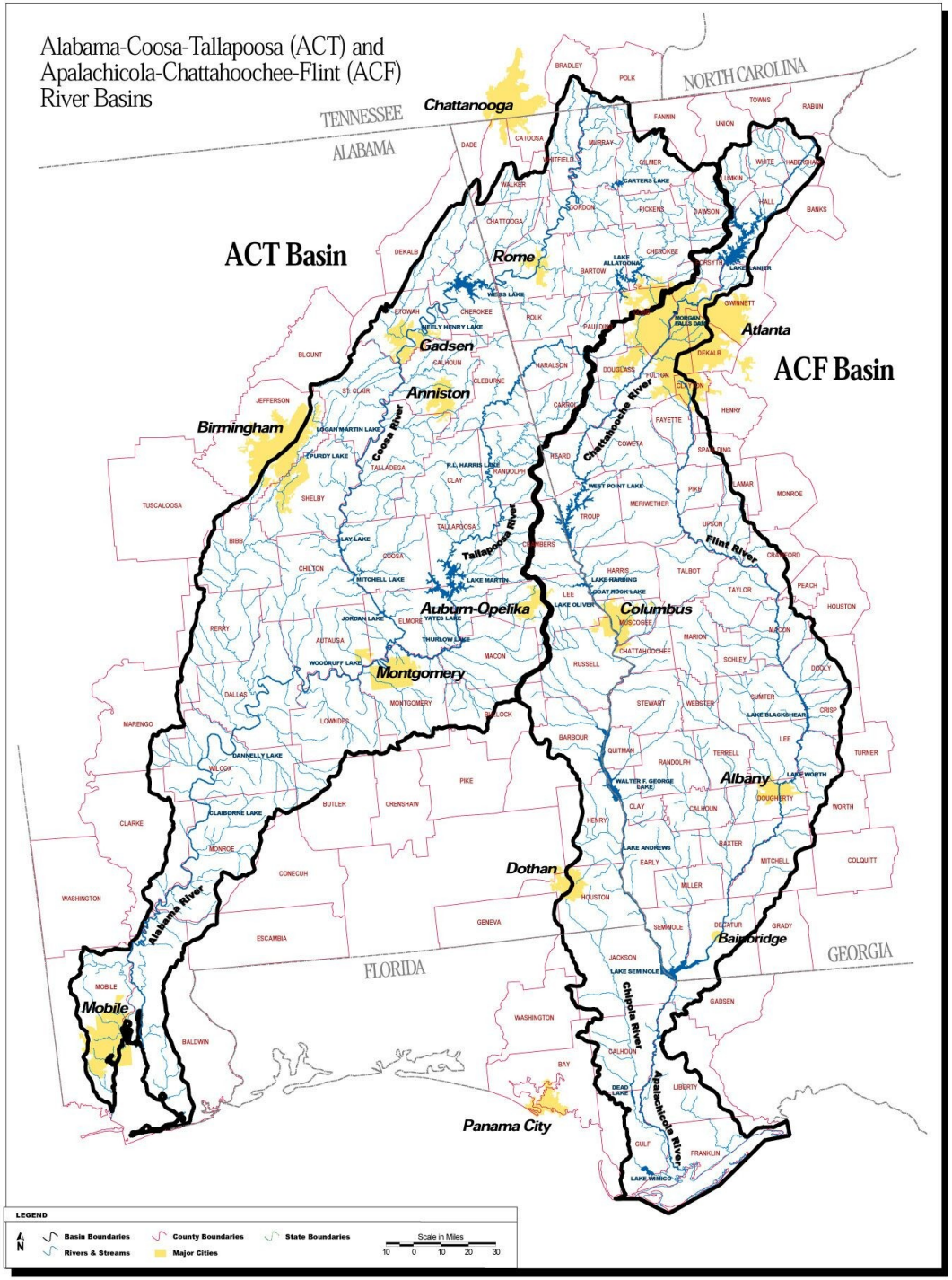


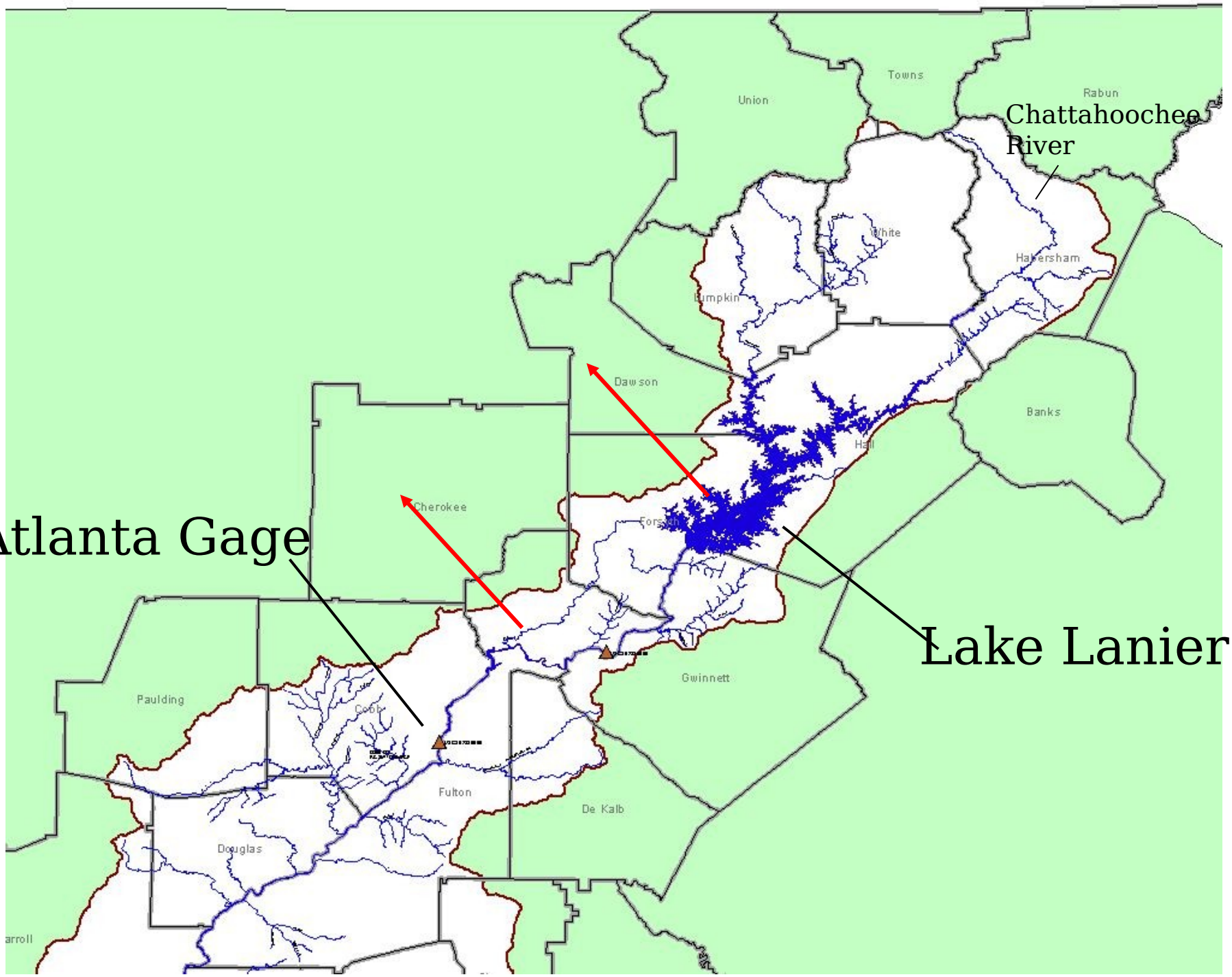
Firm Yield Curve

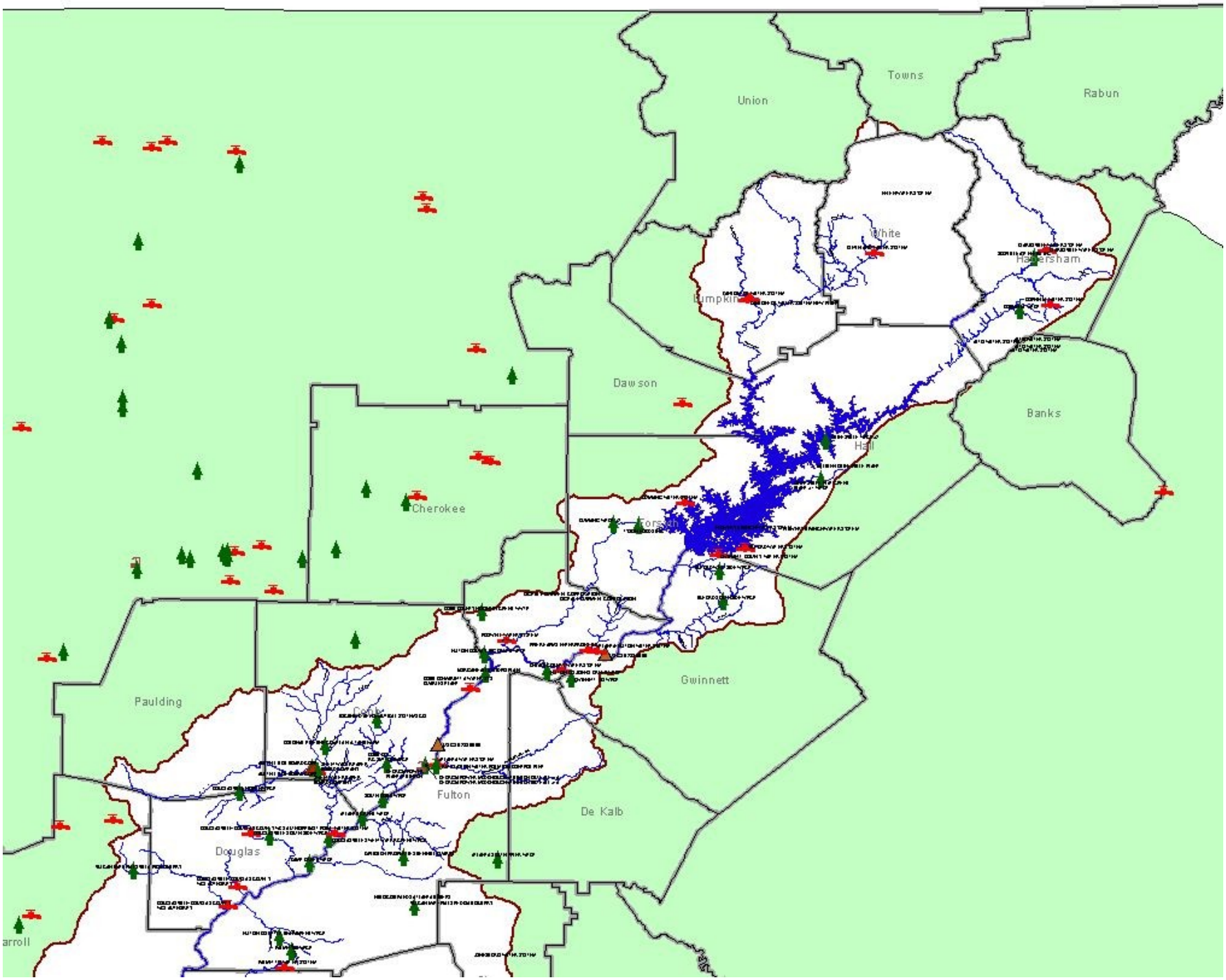


Case Study #1

- ACF Water Allocation Formula
  - Lake Lanier has 65% of basin storage
  - Water supply demand increase from 1,415 cfs to 1,842 cfs by year 2030 (30% increase).


Alabama-Coosa-Tallapoosa (ACT) and
Apalachicola-Chattahoochee-Flint (ACF)
River Basins
ACT Basin
ACF Basin
TENNESSEE
ALABAMA
NORTH CAROLINA
FLORIDA
GEORGIA
Chattanooga
Rome
Gadsen
Anniston
Birmingham
Atlanta
Auburn-Opelika
Columbus
Montgomery
Albany
Dothan
Bainbridge
Mobile
Panama City
Coosa River
Tallapoosa River
Chattahoochee River
Flint River
Alabama River
Chipola River
Apalachicola River
LEGEND
Basin Boundaries
Rivers & Streams
County Boundaries
Major Cities
State Boundaries
Scale in Miles
10 0 10 20 30


Towns
Union
Rabun
Chattahoochee River
White
Habersham
Lumpkin
Dawson
Banks
Hall
Cherokee
Forsyth
Atlanta Gage
Lake Lanier
Gwinnett
Paulding
Cobb
Fulton
De Kalb
Douglas
arroll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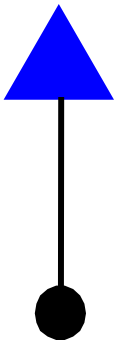
De Kalb
Douglas
arroll

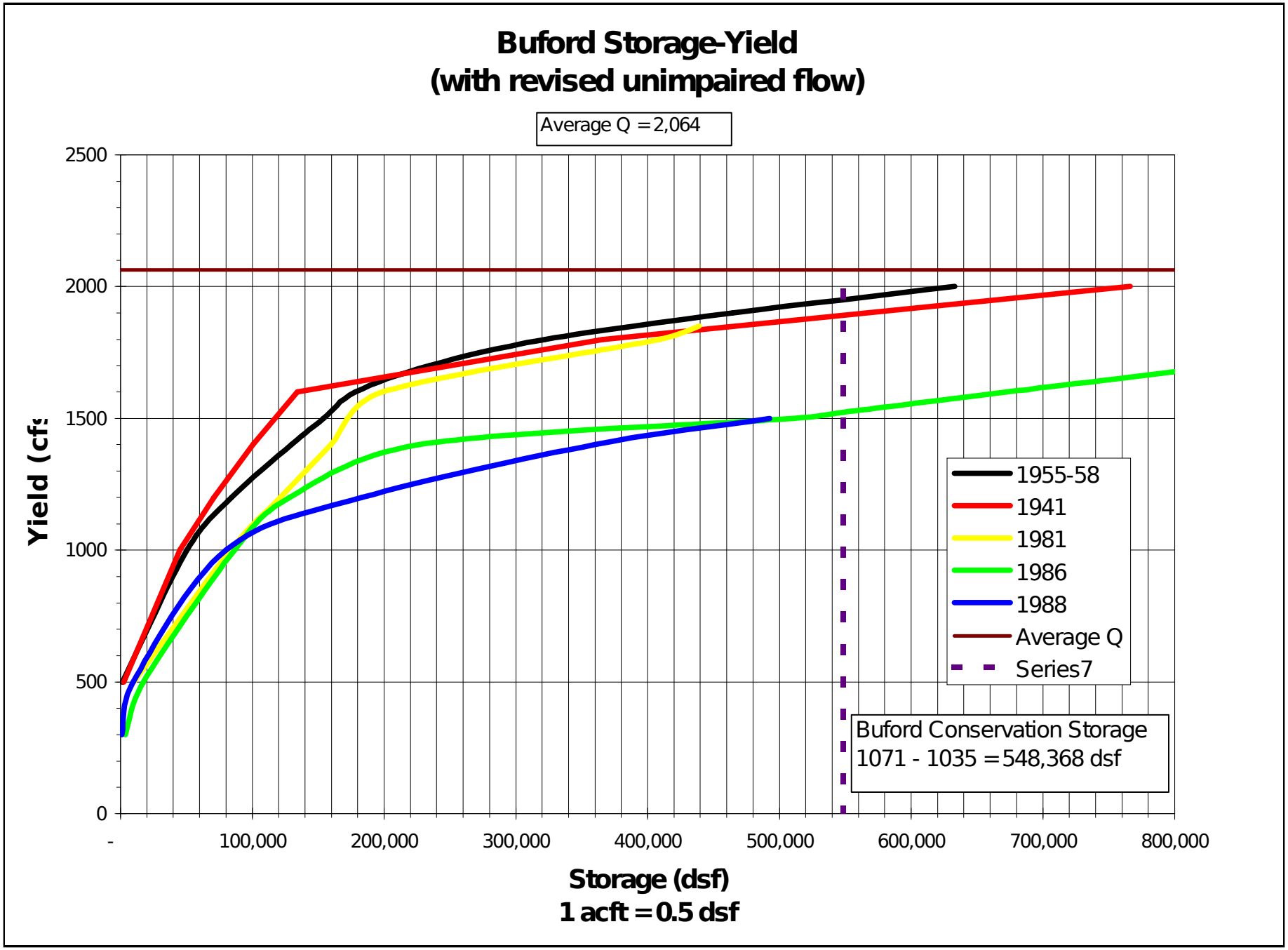
Chattahoochee Demands

Year	Lake Lanier Withdrawal	Chattahoochee River Withdrawal	Water Quality Needs	Total
1999	120 186	310 480	485 750	915 MGD 1,416 cfs
2030	297 460	408 632	485 750	1190 MGD 1,842 cfs

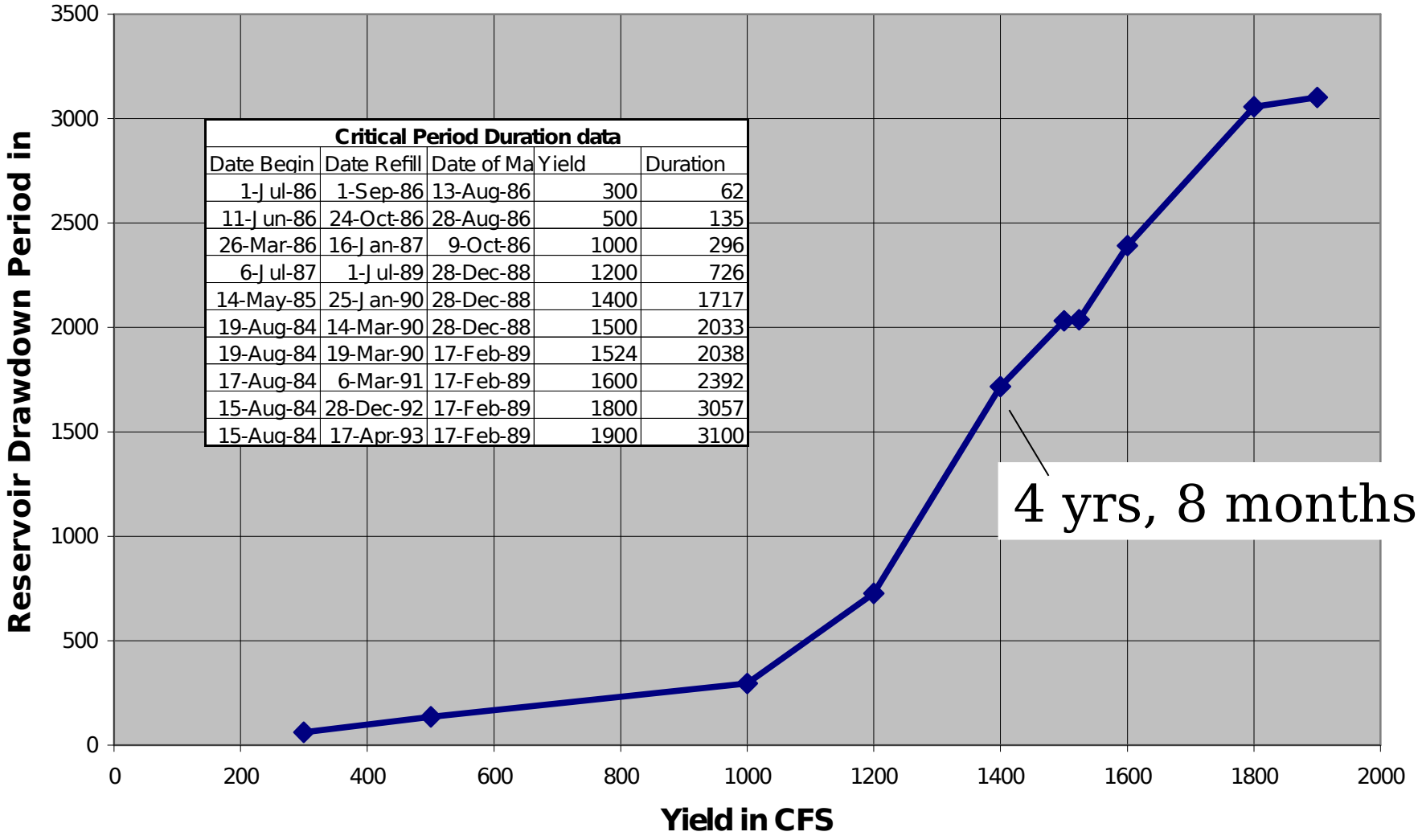
Objective



- Determine if enough storage exist to meet future demands
  - Demands
    - Water supply (lake and river withdrawal)
    - Water quality


Buford Storage-Yield
(with revised unimpaired flow)
Average Q = 2,064
2500
2000
1500
1000
500
0
Yield (cfs
-
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Storage (dsf)
1 acft = 0.5 dsf
1955-58
1941
1981
1986
1988
Average Q
Series7
Buford Conservation Storage
1071 - 1035 = 548,368 dsf

Lanier Critical Period Duration



Critical Period Duration data

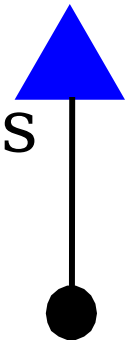
Date Begin	Date Refill	Date of Ma	Yield	Duration
1-Jul-86	1-Sep-86	13-Aug-86	300	62
11-Jun-86	24-Oct-86	28-Aug-86	500	135
26-Mar-86	16-Jan-87	9-Oct-86	1000	296
6-Jul-87	1-Jul-89	28-Dec-88	1200	726
14-May-85	25-Jan-90	28-Dec-88	1400	1717
19-Aug-84	14-Mar-90	28-Dec-88	1500	2033
19-Aug-84	19-Mar-90	17-Feb-89	1524	2038
17-Aug-84	6-Mar-91	17-Feb-89	1600	2392
15-Aug-84	28-Dec-92	17-Feb-89	1800	3057
15-Aug-84	17-Apr-93	17-Feb-89	1900	3100

Buford Dam Critical Yield

- Graphical Method
- Unimpaired Flow 1939-1993
- Critical Period 1980’s
- Buford Conservation Storage 549,000 dsf

  (1071-1035)
- Critical Yield = 1,524 cfs (w/o evap)

GA ACF Proposal



- Upper 2030 Chattahoochee Withdrawals
  - Lake Lanier withdrawal 460 (297 mgd)
  - Chat River withdrawal 632 (408 mgd)
  - Water Quality needs 800 (548 mgd)

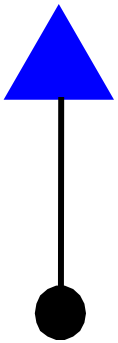
  Total 1,892

  Evaporation ? (100-200 cfs)

  Preliminary analysis; shortage of 368 cfs

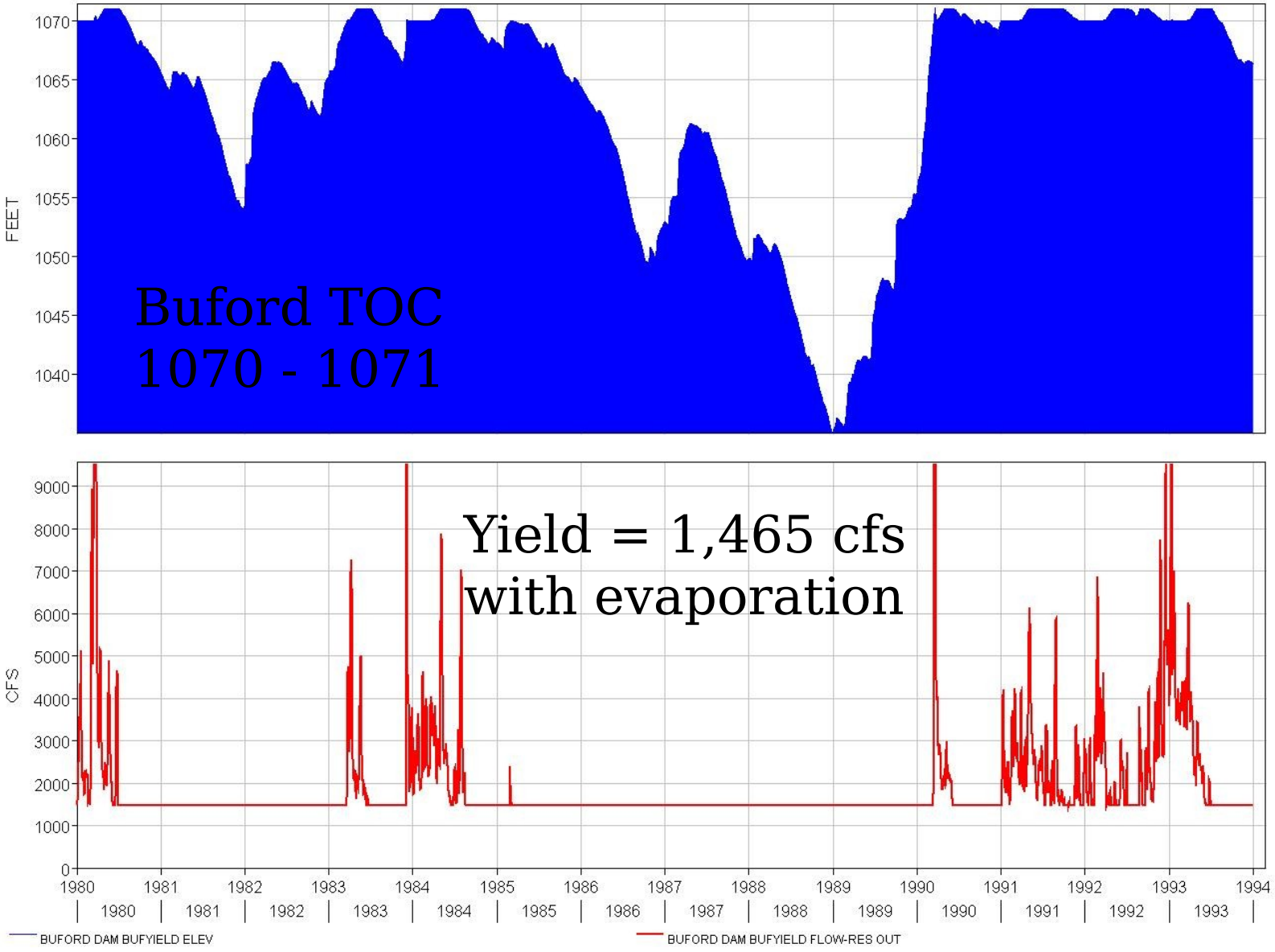
Chattahoochee River at Atlanta Safe Yield Model

File: ATLY



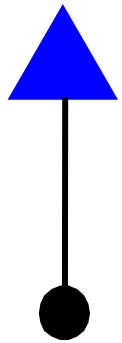
- Prime flow (local inflow + Lanier release) = 1,985 cfs
- No other operational targets except 10,000 cfs limiting flood release
- Conservation pool limits = 1035.0, 1071.0
- Seasonal drawdown to 1070.0
- Demand equals 1,892 cfs (no shortages)

Buford Yield



Buf-to-Atl Base Flow Estimate

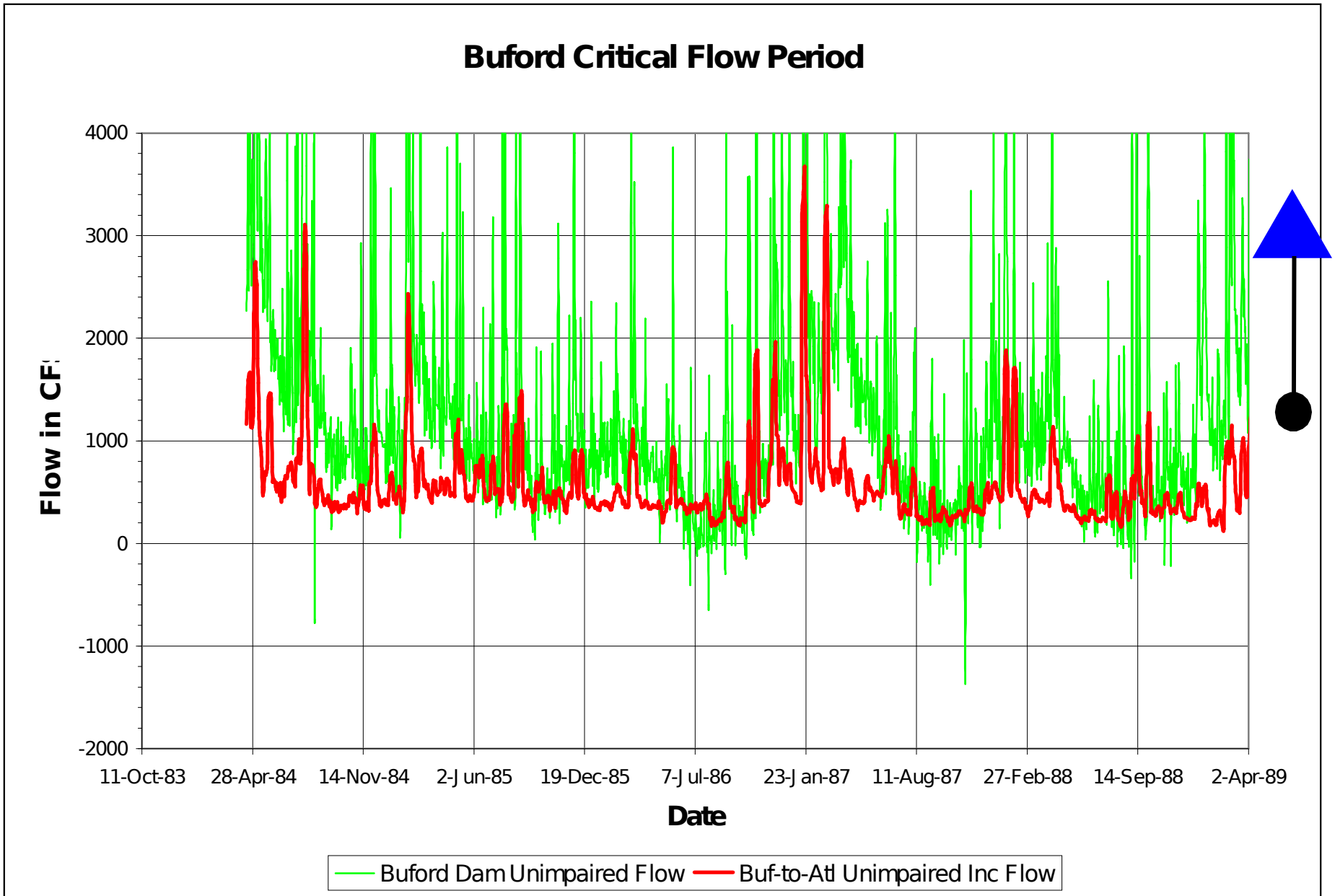
Location	DA (mile^2)	1986 AADF (cfs)	CFSM
Sope Ck	29.2	21.8	0.75
Suwanee Ck	46.8	31.7	0.68
Big Ck	72	45.5	0.63
			Ave = 0.69



Buford to Atlanta DA = 410 miles2

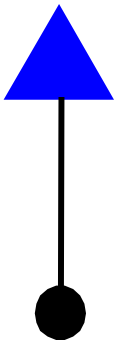
Dependable Buf-Atl Local Flow

410 x 0.69 = 280 cfs


Buford Critical Flow Period
Flow in CF
4000
3000
2000
1000
0
-1000
-2000
11-Oct-83
28-Apr-84
14-Nov-84
2-Jun-85
19-Dec-85
7-Jul-86
23-Jan-87
11-Aug-87
27-Feb-88
14-Sep-88
2-Apr-89
Date
Buford Dam Unimpaired Flow
Buf-to-Atl Unimpaired Inc Flow

Potential Shortage

Year	Demands	Yield + 200	Potential Shortage
2010	1600	1665	
2020	1753	1665	88
2030	1842	1665	177



Assume Buf – Atl base flow of 200 cfs

Analysis presented to states but ignored

Buford Dam Critical Yield

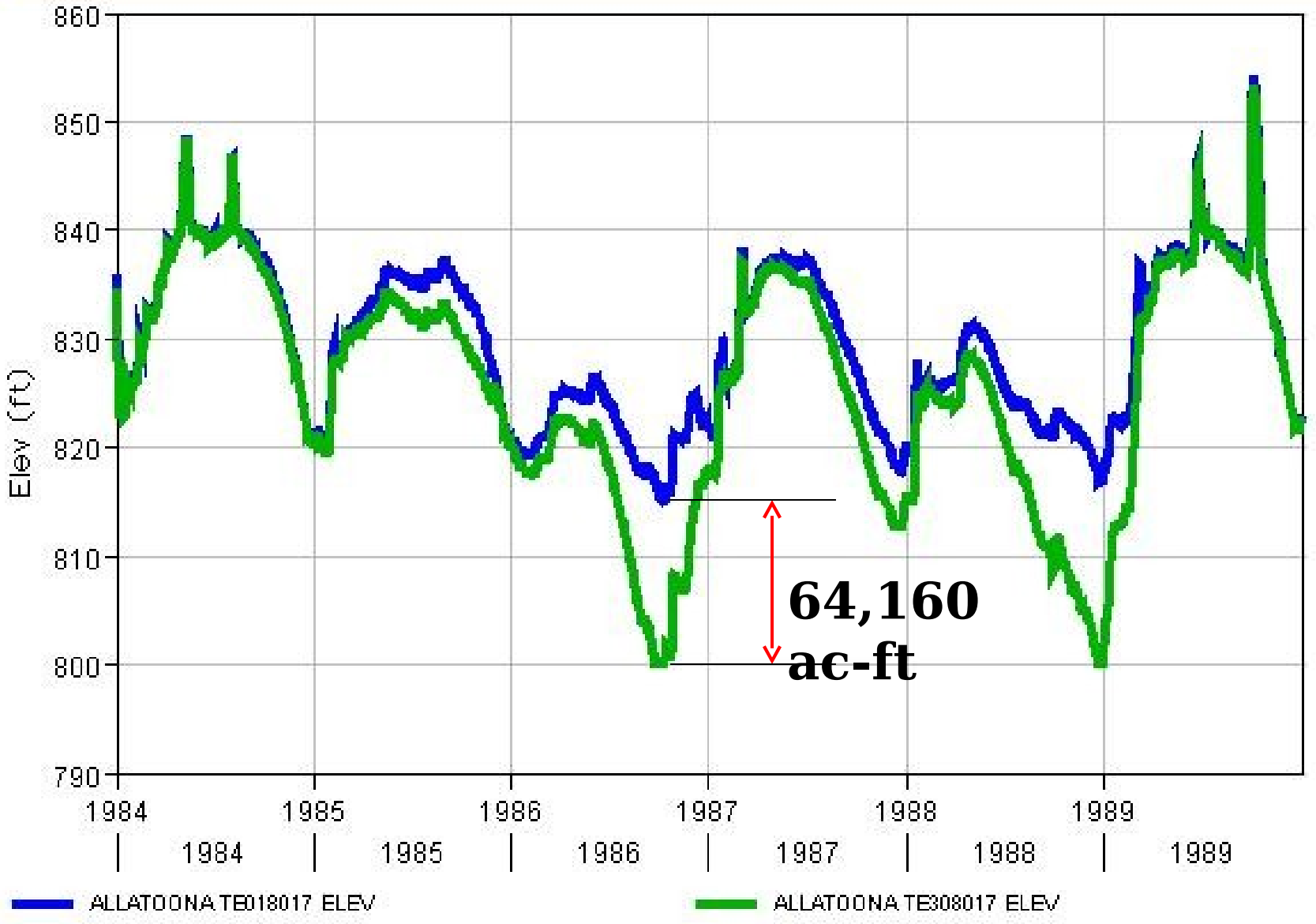
- What if Storage Increased?
- Raise T.O.C. to 1080
- Buford Conservation Storage 735,000 dsf
  (1080-1035)
- Critical Yield = 1,638 cfs (w/o evap)

- **34% increase in storage, 7% increase in yield**

Case Study #2

- ACT Allocation Formula
- Reallocation to meet 2030 demands
- Model run using critical period
  - Existing Conditions (2001 demands)
  - Future Conditions (2030 demands)
- Measure the additional storage to meet increase demand
- Economic analysis

Allatoona Required Storage



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